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NIANTIC LIGHTSHIP BASED AUGMENTED REALITY FOR ENHANCING IPAS LEARNING IN ELEMENTARY EDUCATION

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Abstract— *Abstract concepts in Natural and Social Sciences (IPAS), particularly the complete metamorphosis of butterflies, often present visualization challenges for elementary school students. This study addresses this issue by developing an interactive markerless Augmented Reality (AR) application using Niantic Lightship ARDK. The application employs Meshing and Occlusion features to enhance spatial immersion. Following the Multimedia Development Life Cycle (MDLC) method, a one-shot case study design (N=22) was used to evaluate the software's functional feasibility and the students' basic cognitive mastery. Functional testing across various mid-range Android devices indicated technical stability, confirming that advanced AR features can operate on standard hardware. Expert validation rated the media as "Highly Feasible" with a maximum score. Preliminary testing on student learning outcomes yielded an average post-test score of 94.09% with a 90.9% classical mastery level. Although limited by a small sample size and the absence of a control group, these findings suggest that the developed AR application is functional and contributes to student comprehension in IPAS learning.*

Keywords*: Augmented Reality, Butterfly Metamorphosis, Learning Media, MDLC, Niantic Lightship ARDK.*

Intisari— *Konsep abstrak dalam Ilmu Pengetahuan Alam dan Sosial (IPAS), khususnya metamorfosis sempurna kupu-kupu, seringkali menjadi tantangan visualisasi bagi siswa sekolah dasar. Penelitian ini menjawab permasalahan tersebut dengan mengembangkan aplikasi Augmented Reality (AR) interaktif tanpa penanda (markerless) menggunakan Niantic Lightship ARDK. Aplikasi ini memanfaatkan fitur Meshing dan Occlusion untuk meningkatkan imersi spasial. Mengikuti metode Multimedia Development Life Cycle (MDLC), penelitian ini menggunakan desain studi kasus sekali tembak (one-shot case study) (N=22) untuk mengevaluasi kelayakan fungsional perangkat lunak dan penguasaan kognitif dasar siswa. Pengujian fungsional pada berbagai perangkat Android kelas menengah menunjukkan stabilitas teknis yang tinggi, yang menegaskan aksesibilitas fitur AR canggih pada perangkat keras standar. Selain itu, validasi ahli menilai media ini sebagai "Sangat Layak" dengan skor maksimal. Pengujian awal terhadap hasil belajar siswa menghasilkan skor rata-rata pasca-tes sebesar 94,09% dengan tingkat ketuntasan klasikal sebesar 90,9%. Meskipun dibatasi oleh ukuran sampel yang kecil dan tidak adanya kelompok kontrol, temuan awal ini menunjukkan bahwa aplikasi AR yang dikembangkan berfungsi dengan andal dan berhasil mendukung pemahaman siswa dalam pembelajaran IPAS.*

Kata Kunci*: Augmented Reality, Metamorfosis Kupu-Kupu, Media Pembelajaran, MDLC, Niantic Lightship ARDK.*

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INTRODUCTION

Teaching abstract and dynamic concepts in natural, social, and scientific fields (IPAS), such as butterfly metamorphosis, often poses a challenge for primary school education. Pupils are required to visualise the changes from egg to caterpillar to chrysalis to butterfly. This process relies on learning media as a means of conveying information and facilitating the learning process [1]. Reliance on conventional learning media, such as textbooks with pictures, often fails to present the process in its entirety, thereby hindering conceptual understanding and reducing students' interest in learning [2]. This learning challenge was confirmed through interviews and observations with a teacher at SD Muhammadiyah Karangbendo, which showed that the current media is not yet able to provide a clear picture of the metamorphosis process [3]. This was confirmed by the teacher, who noted that students tended to be passive and found it challenging to understand the stages of metamorphosis solely from pictures. Furthermore, students showed a high interest in technology-based learning media, presenting an opportunity for intervention [4].

In response to this challenge, the educational literature has explored various media. While traditional digital media, such as videos or interactive flipbooks, have been used, they often lack the depth of immersion. Consequently, Augmented Reality (AR) has gained traction for its potential to visualize complex scientific concepts [5]. Although several AR applications for education already exist, many of them still use marker-based systems that limit interaction to visual markers. These systems require physical markers (like a QR code or a specific textbook image) to function, which limits flexibility and interaction within a dynamic classroom environment [6], [7].

While other markerless applications exist, this study introduces a new approach by integrating the Niantic Lightship Augmented Reality Development Kit (ARDK), a relatively new and advanced platform for educational research. This technology enables real-time environmental meshing (dynamic 3D mapping of the environment) and occlusion (virtual objects can hide behind real objects), creating a much more immersive experience. The novelty of this research lies in the combination of this specific technology with a quantitative analysis of student learning outcomes at the elementary school level. This area still requires further exploration. The development method applied is the Multimedia Development Life Cycle (MDLC) due to its systematic structure and suitability for multimedia products [8].

This study aims to develop an AR application to help students recognize and clearly visualize the complete metamorphosis process of butterflies [9]. Augmented Reality (AR) is a technology that combines virtual information and the real world. It enables interactive, three-dimensional visualization of abstract concepts to improve human interaction with computers in the real world [10], [11]. It is hoped that this application will make the learning process more interesting and compelling, especially in IPAS learning on the complete metamorphosis of butterflies. Based on the problem identification and the potential of Niantic Lightship ARDK technology, this study hypothesizes that the integration of markerless Augmented Reality will produce a highly feasible learning media that effectively supports students in achieving the minimum cognitive mastery criteria. By employing a post-test-only design, this research focuses on determining functional viability and basic student comprehension, rather than testing comparative improvement against conventional teaching methods.

MATERIAL AND METHODS

The study adopted the Multimedia Development Life Cycle (MDLC), which comprises six stages: Concept, Design, Material Collecting, Assembly, Testing, and Distribution [12]. To identify key issues and functional requirements, preliminary data were gathered during the Concept stage through observation and interviews. Following this, the design stage focused on developing the system architecture and user interface (UI), incorporating 3D models and Unified Modeling Language (UML) diagrams. Material Collection consisted of gathering all necessary pre-made materials. During the Assembly stage, these materials were implemented and integrated into the Android-based AR application using the Unity game engine, the Niantic Lightship ARDK, and C# programming for navigation [13].

The research was conducted at Muhammadiyah Karangbendo Elementary School in Yogyakarta. The participants consisted of 22 third-grade students (aged 8–9 years) from a single intact classroom (Class 3A). This specific class was selected based on school administration recommendations and practical accessibility for the case study. Recognizing the small and localized sample size, this intact-classroom approach was deliberately chosen as a preliminary prototype evaluation rather than a large-scale efficacy trial. This design provides context-specific insights into the initial implementation of the developed AR learning media within an exploratory educational context.

Additionally, to ensure methodological consistency, the evaluation strictly focused on two main parameters: the software's functional feasibility and the students' cognitive learning outcomes. Data collection was executed in two phases. Phase one involved initial interviews with the classroom teacher and observations of conventional learning activities to identify core instructional problems and define functional system requirements. Phase two, conducted after application development, employed three primary evaluation instruments. First, functional Black Box Testing assessed system stability.

Second, a media feasibility questionnaire using a Likert scale was evaluated by a subject matter expert (the classroom teacher). While utilizing a single expert evaluator is acknowledged as a limitation in this preliminary phase, it provided essential initial feedback. Third, a post-test consisting of 10 multiple-choice items was administered to measure student learning outcomes [14]. To ensure item validity and content coverage, these post-test items were constructed based on the Kurikulum Merdeka (IPAS) standards and content-validated by the teacher prior to administration. The scoring procedure assigned an equal weight to each item, yielding a maximum possible score of 100.

Data analysis applied a quantitative descriptive approach [15]. Questionnaire data were converted into percentage scores to determine the level of media feasibility. At the same time, post-test results were analyzed to calculate the mean score and the classical completion rate, defined as the percentage of students achieving scores above the Minimum Passing Criteria (MPC) of 75 [16]. The evaluation of student learning outcomes utilized a one-shot case study design (post-test only) without a control group. This study prioritizes the development and functional feasibility of software. Therefore, this study acknowledges the absence of a pre-test and control group as methodological limitations, so that the analysis focuses on the level of student mastery and final competence, rather than on measuring gains caused solely by the intervention.

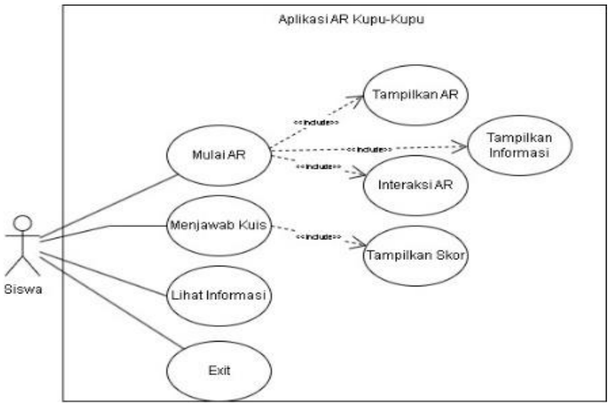
RESULT AND DISCUSSION

This section presents the results of the product development process and user testing, followed by an analytical discussion of the findings, implications, and limitations of the study.

Application Design and Features

The application's functionality was designed based on user requirements identified in the concept stage. To illustrate this application, a use case diagram is presented in Figure 1. This diagram illustrates the main interaction flow, showing the Student (as the actor) and their interactions with the system's primary functions. The main use cases depicted are Mulai AR (Start AR), Menjawab Kuis (Answer Quiz), Lihat Informasi (See Information), and Exit. The diagram further details the sub-features included within these main functions; for example, the Start AR use case includes functions to Display AR, Display Information, and enable AR Interaction, while the Answer Quiz use case includes Display Score, thus providing a clear blueprint of the application's architecture [17].

From an instructional design perspective, this Use Case structure prioritizes a student-centered approach by simplifying the navigation flow to match the cognitive level of elementary students. The clear separation between the 'Start AR' (exploration phase) and 'Answer Quiz' (evaluation phase) allows students to first construct knowledge through immersive interaction without distraction, before assessing their understanding. Furthermore, the inclusion of the 'Display Score' mechanism provides immediate feedback, a critical component in educational software that reinforces learning retention and maintains student motivation.



Source: (Research Results, 2025)

Figure 1. Use Case Diagram

The development process, following the MDLC method, successfully produced a functional Android application. Figma was used to design the user interface (UI), including icons and navigation buttons, to ensure it was easy to use and understand for the target users [18]. The application was built using Unity Engine and Niantic Lightship ARDK. Niantic Lightship ARDK is a technology designed for developers to develop Augmented Reality with realistic and immersive experiences integrated with

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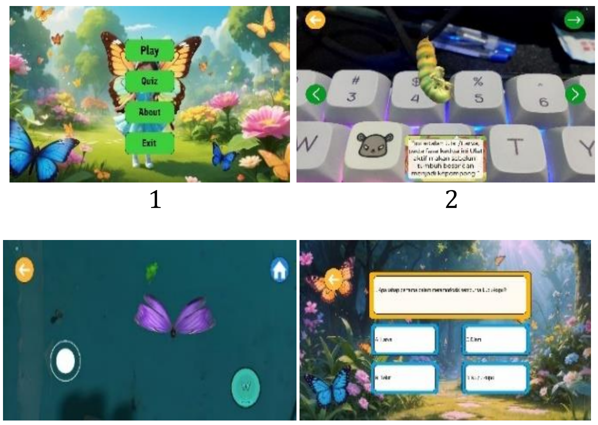
the real world, offering capabilities in supporting environmental understanding, determining position or location, and interaction between more than one user [19]. The 3D model and animation were created using Blender [20].

This final application displays several main pages, including the main menu, quiz module, about page, and core AR module [21]. Figure 2 illustrates these core features in action. Panel 1 shows the Main Menu, which serves as the main navigation center. The AR module itself is divided into two modes. Panel 2 is the AR recognition module, where a 3D model (e.g., a caterpillar) is displayed with a 3D description text box. Panel 3 shows the Interactive AR module, where users can control the butterfly's movements using a joystick and increase the number of 3D butterfly objects.

Panel 4 shows a separate Interactive Quiz module, which students use to test their knowledge after using the material introduction and interaction AR modes. Beyond merely presenting navigation menus, the implementation of the markerless AR interface in these panels demonstrates how the system dynamically anchors 3D models to physical surfaces within the real-world environment. Unlike conventional media, this spatial integration allows students to observe the intricate stages of butterfly metamorphosis from multiple angles without being restricted by printed markers. This visual evidence provides support for the study's premise that Niantic Lightship ARDK can offer a concrete representation of abstract biological concepts, thereby addressing the limitations of traditional 2D textbooks.



Source: (Research Results, 2025)

Figure 2. Result of application

Technical Implementation and Performance

The development process resulted in a functional Android application called "AR Butterfly Metamorphosis." The integration of Niantic Lightship ARDK is at the core of its functionality. Researchers utilized the Meshing feature to create a dynamic 3D mesh of the real-world environment, allowing virtual objects to navigate surfaces. Additionally, the Occlusion feature was implemented to enable virtual objects to appear behind real-world objects, thereby significantly enhancing user immersion [19].

Black Box Testing

Black Box Testing is a software testing method that focuses on evaluating system functionality based on external specifications without requiring knowledge of the code structure or software design. The testing method used in this study is employed to verify the functionality of each feature listed in Table 1. The primary goal is to ensure that each user input produces the desired output and to identify any bugs in the application. This requires the development of test cases for each feature, such as ensuring that the AR visualization is successfully launched by clicking the Play button, that quiz answers are submitted correctly by clicking the Answer button on the options, and that all Back and Home buttons lead to the appropriate scenes. To verify stability and compatibility, functional testing was then carried out on four distinct mid-range devices (D1-D4).

The selection of these specific devices for functional testing was deliberate. Black Box Testing was conducted to evaluate the system's functionality based on external specifications, ensuring that each user input produces the desired output without examining the internal code structure. The test procedures involved systematically executing 13 core features (test cases) outlined in Table 1, such as launching AR visualizations, submitting quiz answers, and navigating between scenes, to identify any functional errors or bugs. Rather than utilizing high-end flagship smartphones, this study intentionally selected mid-range Android devices to accurately represent the typical hardware accessible to elementary school students and their families.

Specifically, the devices were chosen to cover a wide range of operating systems and varying RAM capacities: Device 1 (D1) Redmi Note 10 5G (Android 13, 8 GB RAM), Device 2 (D2) Xiaomi Pad 6 (Android 14, 8 GB RAM), Device 3 (D3) Samsung S21 FE (Android 12, 8 GB RAM), and Device 4 (D4) Samsung A50 (Android 11, 6 GB RAM) [22]. This selection aims to validate that the resource-intensive features of Niantic Lightship, particularly real-time Meshing and Occlusion, can function smoothly on standard hardware. Confirming this accessibility is critical to minimizing potential digital divide barriers in educational adoption.

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Table 1. Black Box Testing

Number	Feature	Description	D1	D2	D3	D4
1	Main Menu	Display main menu	✓	✓	✓	✓
2	Play Button	Open AR visualization	✓	✓	✓	✓
3	Quiz Button	Display interactive quiz	✓	✓	✓	✓
4	About Button	Display information	✓	✓	✓	✓
5	Exit Button	Close application	✓	✓	✓	✓
6	Back Button	Return to previous scene	✓	✓	✓	✓
7	Next Button	Proceed to the next scene	✓	✓	✓	✓
8	Restart Button	Reset quiz	✓	✓	✓	✓
9	Home Button	Return to main menu	✓	✓	✓	✓
10	Answer Question	Submit quiz answer	✓	✓	✓	✓
11	Spawn Button	Add butterflies object	✓	✓	✓	✓
12	Score Result	Display final score	✓	✓	✓	✓
13	Answer Button	Show correct/incorrect answer	✓	✓	✓	✓

Source : (Research Results, 2025)

The functional testing results in Table 1 show a perfect success rate, with a total of 52 test cases successfully executed on all four devices. This result carries significant technical implications. It confirms that the optimization strategies applied during development successfully managed the memory overhead typically associated with ARDK's Meshing and Occlusion features. The stable performance on Device 4 (Samsung A50), is noteworthy. It indicates backward compatibility and suggests that the application can operate on devices with lower specifications, which is relevant for broader classroom use.

Likert Scale

Following the Black Box Testing, the next step is to evaluate its pedagogical feasibility. To achieve this, quantitative validation was carried out using a Likert scale questionnaire. This method was chosen to measure the expert's stance and perception of specific quality criteria [14]. The questionnaire was assigned to one expert on the subject matter (a third-grade teacher), who was best qualified to evaluate the accuracy and compatibility of the content. The expert rated the application on five key criteria (detailed in Table 2) using a 5-point scale: 5 = Strongly Agree (SA), 4 = Agree (A), 3 = Neutral (N), 2 = Disagree (D), and 1 = Strongly Disagree (SD).

Table 2. Questionnaire

No	Question	SA	A	N	D	SD	Score	percentage
1	The material on the butterfly life cycle in the application is presented clearly and is easy to understand.	✓					5	100%
2	The 3D visualisation in the application helps students understand the stages of butterfly metamorphosis in detail.	✓					5	100%
3	The text information displayed in the application corresponds to the stages of butterfly metamorphosis.	✓					5	100%
4	The interactive quizzes in the application help students understand the material on butterfly metamorphosis.	✓					5	100%
5	The material in the application makes students interested in learning about the butterfly life cycle	✓					5	100%

Source : (Research Results, 2025)

The validation results in Table 2 show that the developed AR application obtained a perfect feasibility score (100%) across all evaluated indicators from the subject teacher. While this suggests that the AR visualization aligns well with the learning objectives and possesses an intuitive UI design, it is crucial to interpret this perfect score with caution. The reliance on a single expert evaluator constitutes a methodological limitation, as it restricts the statistical reliability of the assessment and introduces the potential for subjective bias. Therefore, this 100% rating should be viewed strictly as a preliminary indicator of pedagogical feasibility rather than a definitive, generalized validation. Future iterations of this research must involve a broader panel of media and material experts to

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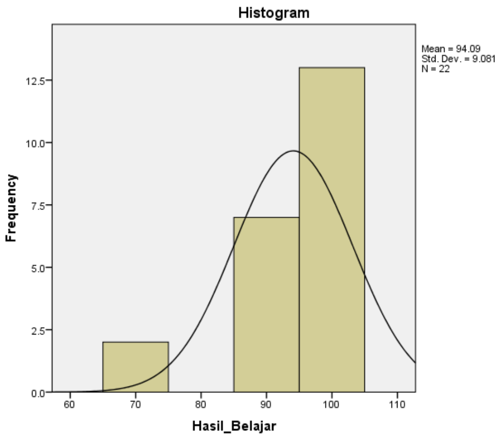
ensure a more robust and unbiased evaluation. Evaluated by a subject matter expert (classroom teacher) using a Likert scale questionnaire, the media achieved a 100% score ("Highly Feasible"). This effectively confirms its content validity and pedagogical appropriateness.

Learning Outcome Results

To measure the application's potential, a 10-question post-test was administered to the 22 student participants after they used the media. The frequency distribution of these post-test scores is presented in the histogram in Figure 3.



Source: (Research Results, 2025)
Figure 3. Histogram Diagram

The post-test results reveal a high level of student mastery. As shown in the histogram (Figure 3), the analysis yielded a mean score of 94.09 with a standard deviation of 9.061. While the classical mastery rate reached 90.9%, the distribution shows a pronounced ceiling effect, with the majority of scores clustered at the maximum limit. This suggests that while the AR application successfully facilitates basic comprehension of the butterfly life cycle, the current 10-item instrument may have a low difficulty index. The high scores confirm the media's effectiveness for fundamental visualization, but future studies should implement more complex assessment items to better differentiate higher-order thinking skills and avoid potential measurement bias.

This study distinguishes itself from prior research by implementing advanced markerless technology using Niantic Lightship, addressing the limitations of traditional AR methods. Previous studies, such as [6], relied heavily on marker-based tracking which requires physical cards, thereby restricting students' movement and interaction space. In contrast, our findings demonstrate that Niantic's meshing and occlusion capabilities allow for a more immersive and flexible learning environment on mid-range devices without the need for physical props. Furthermore, the high student completion rate (90.9%) in this study aligns with findings by [16], confirming that interactive 3D visualization significantly aids in providing clear and accessible representations of abstract concepts like metamorphosis. However, unlike [5] which focused on standard AR implementations without environmental interaction, this research validates that such advanced features are now accessible on standard Android smartphones, broadening the potential for mass adoption in elementary schools

Discussion

This study integrates Niantic Lightship ARDK, a next-generation markerless platform, into IPAS Learning, offering novel insights into the practical deployment of advanced AR features in real classroom settings. While prior AR applications for biology education, such as Khanan and Wardhani [5], have shown conceptual progress using Unity AR Foundation, they focused primarily on standard AR implementations without fully exploring the core capabilities of real-time environment modeling or object occlusion. In contrast, this study provides a technical analysis of these advanced features, revealing that Lightship's meshing capabilities allow virtual objects to interact realistically with physical obstacles—a feature previously underutilized in IPAS learning [4], [8].

Furthermore, this study distinguishes itself from earlier marker-based implementations. Unlike systems that rely on physical cards and restrict interaction space [6], [7], the markerless design of this application enables interaction on any surface (e.g., table, floor, or hand). This transition from controlled AR to context-aware AR aligns with constructivist principles, where learners actively build knowledge through embedded environmental interactions [10], [11]. In terms of learning outcomes, the high student completion rate (90.9%) observed in this study aligns with findings by Rahmawati et al. [16]. However, because this preliminary study did not employ a specific cognitive load instrument, these high scores are interpreted strictly as evidence that the interactive 3D visualization successfully provides a clear and accessible representation of abstract concepts, which facilitated students in achieving the basic cognitive mastery criteria.

Despite these positive outcomes, it is crucial to acknowledge the study's limitations and challenges regarding the digital divide. First, as a case study with a small sample size (N=22) and no control group, the findings demonstrate potential and feasibility rather than rigorous causal effectiveness. Second, the deployment of such advanced AR mechanics requires careful consideration of the environmental context. As highlighted by da Silva et al. [23], while Niantic's technologies offer immersive affordances, their dependence on specific location-based features and hardware capabilities (e.g., gyroscope and RAM) can limit generalizability and accessibility in diverse educational settings. Consequently, while the application is highly effective for the tested group, mass adoption requires addressing these infrastructure barriers to ensure equitable learning opportunities.

CONCLUSION

This study demonstrated the development and validation of a feasible AR learning application using Niantic Lightship ARDK. The findings indicate that markerless AR can provide accessible visualizations that facilitate students' basic cognitive mastery of abstract scientific concepts. For educators, the results highlight both the instructional potential of AR and the practical challenges posed by hardware requirements, which may contribute to a digital gap. For researchers and developers, the study suggests that future work should not only advance AR sophistication but also prioritize optimizing immersive features (such as Meshing and Occlusion) for devices with lower specifications. Such optimization is important to promote equitable access across diverse classroom environments. While this case study shows promise, future research should employ more rigorous designs, including pre-/post-tests and control groups, to validate these initial findings on a larger scale.

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